Planned Observation by Venus Climate Orbiter

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Current status

- Flight model integration test is being conducted. Vibration test and electrical performance tests have been completed successfully. Thermal vacuum test is planned this month.
- The spacecraft will be shipped to the launch site in March.

Fitting test with PAF (Payload Attachment Fitting)

Vibration test
Longwave InfraRed camera (LIR)

Ultraviolet Imager (UVI)

Lightning and Airglow Camera (LAC)

1μm Camera (IR1)

2μm Camera (IR2)

Ultra Stable Oscillator (USO)

Digital Electronics (DE)

Side panel of spacecraft

283,365nm

~10μm

550~770nm

Ultra Stable Oscillator

Digital Electronics

Side panel of spacecraft

Longwave InfraRed camera (LIR)

Lightning and Airglow Camera (LAC)
**Venus Climate Orbiter/Akatsuki (PLANET-C project)**

- First Japanese Venus mission

- **Science target:**
  - Mechanism of super-rotation
  - Structure of meridional circulation
  - Meso-scale processes
  - Formation of H2SO4 clouds
  - Lightning
  - Active volcanism, inhomogeneity of surface material
  - Zodiacal light (during cruise)

- **Launch:** May 2010 → **Arrival:** December 2010

- **Mission life:** More than 2 Earth years
Comparative planetary meteorology

Earth
- Hadley cell
- Ferrel cell
- Polar cell
- Westerly wind
- Easterly wind

Venus
- Super-rotation

Mars
- Ferrel cell
- Hadley cell
- Westerly wind
- Easterly wind
- Winter
- Summer

Titan
- Super-rotation
Hypotheses of super-rotation

* Which is working? Any other mechanisms?

* Key parameters: Planetary-scale waves, Meridional circulation, Large-scale turbulence
Cloud processes

- Dynamics of cloud formation, role of meridional circulation in transporting cloud-related species
- Origin of UV markings
- Whether lightening occurs or not

Concept of meteorological satellite

- Capturing global structures with emphasis on the low latitude
  - Wide FOV imaging from equatorial orbit
- Covering spatial scales from meso to global
  - Large-format 2D detectors
- Covering time scales from hours to months
  - Continuous sampling, repeating for all orbits
- Studying vertical structures
  - Multi-wavelength imaging + radio science
Observation from an orbiter

- 4 cameras sounding different altitudes, a high-speed lightning detector, and an ultra-stable oscillator for radio science

- Constructing 3-D model of atmospheric dynamics
<table>
<thead>
<tr>
<th>Instrument</th>
<th>FOV</th>
<th>Detector</th>
<th>Filters</th>
<th>Width</th>
<th>Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-(\mu)m Camera IR1</td>
<td>12</td>
<td>Si-CSD/CCD</td>
<td>1.01 (\mu)m (night)</td>
<td>0.04 (\mu)m</td>
<td>Surface, Clouds</td>
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<tr>
<td></td>
<td></td>
<td>1024 x 1024 pix</td>
<td>0.97 (\mu)m (night)</td>
<td>0.04 (\mu)m</td>
<td>H(_2)O vapor</td>
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<td>0.90 (\mu)m (night)</td>
<td>0.03 (\mu)m</td>
<td>Surface, Clouds</td>
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<td></td>
<td>0.90 (\mu)m (day)</td>
<td>0.01 (\mu)m</td>
<td>Clouds</td>
</tr>
<tr>
<td>2-(\mu)m Camera IR2</td>
<td>12</td>
<td>PtSi-CSD/CCD</td>
<td>1.735 (\mu)m (night)</td>
<td>0.04 (\mu)m</td>
<td>Clouds, Particle size</td>
</tr>
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<td></td>
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<td>1024 x 1024 pix</td>
<td>2.26 (\mu)m (night)</td>
<td>0.06 (\mu)m</td>
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<td>2.32 (\mu)m (night)</td>
<td>0.04 (\mu)m</td>
<td>CO below clouds</td>
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<td>2.02 (\mu)m (day)</td>
<td>0.04 (\mu)m</td>
<td>Cloud-top height</td>
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<td></td>
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<td></td>
<td>1.65 (\mu)m (cruise)</td>
<td>0.3 (\mu)m</td>
<td>Zodiacal light</td>
</tr>
<tr>
<td>UltraViolet Imager UVI</td>
<td>12</td>
<td>Si-CCD</td>
<td>283 nm (day)</td>
<td>15 nm</td>
<td>SO(_2) at cloud top</td>
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<tr>
<td></td>
<td></td>
<td>1024 x 1024 pix</td>
<td>365 nm (day)</td>
<td>15 nm</td>
<td>Unknown absorber</td>
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<tr>
<td>Longwave IR Camera LIR</td>
<td>12</td>
<td>Bolometer</td>
<td>10 (\mu)m (day/night)</td>
<td>4 (\mu)m</td>
<td>Cloud-top temperature</td>
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<td>240 x 320 pix</td>
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<tr>
<td>Lightning &amp; Airglow Camera</td>
<td>16</td>
<td>8 x 8 APD</td>
<td>777.4 nm (night)</td>
<td>4.2 nm</td>
<td>OI lightning</td>
</tr>
<tr>
<td>LAC</td>
<td></td>
<td>(50kHz sampling</td>
<td>552.5 nm (night)</td>
<td>4.7 nm</td>
<td>O(_2) HerzbergII airglow</td>
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<tr>
<td></td>
<td></td>
<td>in lightning mode</td>
<td>557.7 nm (night)</td>
<td>3.1 nm</td>
<td>OI airglow</td>
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<td>630.0 nm (night)</td>
<td>3.5 nm</td>
<td>OI airglow</td>
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<tr>
<td>Ultra-stable oscillator for</td>
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<td></td>
<td>X-band (8.4GHz)</td>
<td></td>
<td>Vertical profiles of T, H(_2)SO(_4) (g), Ne</td>
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<td>Radio Science RS</td>
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</table>
Observations to be conducted during one orbital revolution

- Limb images (~0.5 hour)
- Successive Global images of atmosphere and ground surface (~24 hours)
- Orbital period: 30 hours
- Temperature / H$_2$SO$_4$ vapor / Ionosphere by radio occultation
- Close-up images/ Lightning/Airglow (~3 hours x 2)
Orbital motion synchronized with the super-rotation

A concept similar to geostationary meteorological satellite

(movie provided by M. Odaka)
Wavelengths for cloud-tracking

- **365nm**, cloud top (65km), dayside
  - 365 nm image taken by PVO/OCPP

- **0.9μm**, lower cloud (50km), dayside
  - 0.98 μm image taken by Galileo/SSI

- **2.3μm**, lower cloud (50km), nightside
  - 2.3 um image taken by Galileo/NIMS

- **2.02μm**, cloud top (65m), dayside
  - Cloud altimetry by VenusExpress/VIRTIS

- **10μm**, cloud top (65km), dayside & nightside
  - 8.6 um image taken by Subaru telescope, high-pass filtered

* Cloud top and bottom will be covered on both dayside and nightside.
### Accuracy of wind velocity measurement

<table>
<thead>
<tr>
<th></th>
<th>Individual vectors using images separated by 2 hours (5 px x 5 px resolution)</th>
<th>After smoothing to 30 px x 30 px resolution</th>
<th>Individual vectors obtained by tracking long-lived clouds for 10 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVI</td>
<td>12 km/2h = 1.7 m/s</td>
<td>0.28 m/s</td>
<td>12 km/10h = 0.33 m/s</td>
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<tr>
<td>IR1</td>
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<td>IR2</td>
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<tr>
<td>LIR</td>
<td>53 km/2h = 7.3 m/s</td>
<td>1.2 m/s</td>
<td>53 km/10h = 1.5 m/s</td>
</tr>
</tbody>
</table>

*Note: Variations in wind velocity due to environmental factors.*

*Note: Accuracy improvements observed after smoothing.*
Latitudinal coverage of radio occultation
## Complementary missions

<table>
<thead>
<tr>
<th></th>
<th>VCO/Akatsuki</th>
<th>Venus Express</th>
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</thead>
<tbody>
<tr>
<td><strong>Instruments</strong></td>
<td>5 cameras</td>
<td>3 spectrometers</td>
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<tr>
<td></td>
<td>Radio science</td>
<td>1 camera</td>
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<td>Plasma analyzer</td>
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<td>Magnetometer</td>
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<td>Radio science</td>
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<tr>
<td><strong>Target</strong></td>
<td>Atmospheric dynamics</td>
<td>Atmospheric chemistry and dynamics, Surface processes, Plasma environment</td>
</tr>
<tr>
<td><strong>Orbit</strong></td>
<td>Equatorial</td>
<td>Polar</td>
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</tbody>
</table>

Coordinated observations are being planned.
How to extract Fourier components

- Zonal-mean
- Solar-fixed components
- Traveling planetary-scale waves
- Meso-scale disturbances

Continuous, regular sampling is a key to distinguish these components.
Zonal-mean

- Major axis of the orbit is nearly fixed with respect to the inertial frame. Then, averaging the data obtained during one Venus year (imaging) or half year (radio occultation) gives a zonal-mean on the assumption that the atmospheric state is stable and the dependence on the longitude is negligible.

Solar-fixed components

- The mean state for each local time is obtained by averaging data in a local time-latitude coordinate, and then the zonal-mean is subtracted from it.
Traveling planetary-scale waves

• Subtraction of the local time-fixed structure from individual observations gives traveling components. Amplitudes of waves will be extracted by convolving (in longitude and time) the data with sine waves of varying zonal wavenumber and phase speed.

• Fourier analysis of variables at a specific local time regularly sampled once per orbital revolution also gives temporal spectra.

Meso-scale eddies

• In addition to close-up images near periapsis, development of meso-scale eddies over 1 Earth day can be observed. Distribution of meso-scale structures over the entire cloud layer is obtained by combining data over one super-rotation period.
Bit rate is relatively high during the 1-2 months following VOI (Venus Orbit Insertion).

Well-laid observation plan is needed to reduce the data volume.
Orbit just after VOI

Venus Capture Orbit in Ecliptic Coordinate

- Night global view
- Limitation of solar angle (26.5°)
- Lightning / airglow
- Radio occultation
- Limb view
- Day/night global view
- Radio occultation
- Close-up/ Stereo viewing
Dec 2010  32kbps

Shade

Limitation of solar angle

Earth occultation

telecommunication

peri

apo

30 hours (1 revolution)
Observation programs to be installed in the Sensor DE

<table>
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<tr>
<th>Program Name</th>
<th>Description</th>
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Dec 2010

<table>
<thead>
<tr>
<th>Day viewing</th>
<th>Night viewing</th>
<th>Day viewing</th>
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Total volume: 226MB (130 images)
After compression (x1/3): 75MB
Obs time factor (x3/4): 55MB
< Telemetry rate of 72MB/day
Policy of data reduction

* Frequent sampling is required for wavelengths used for cloud tracking, while it can be relatively sparse for wavelengths used for observing trace gases, cloud microphysical parameters and surface properties.

* Dark frame is subtracted from Venus frames by onboard data processing, and dark frames are not transmitted in the nominal operation phase.

* Lossless compression is the nominal, but lossy compression might also be considered depending on the telemetry rate (under discussion).
Level 0: Uncompressed images

Level 1: Calibrated images with FITS header

Level 2: Calibrated images with FITS header, including geometry information

Level 3: Wind vectors and other higher-level products on longitude-latitude grids in NetCDF format

* Level 2 and Level 3 data will be released to the public with PDS-like label files.
Automatic Level 3 processing

- Limb fitting to precisely determine the direction of camera FOV
- Projection onto longitude-latitude grids assuming typical cloud height (2 levels)
- Cloud tracking by cross correlation method
- Correction of erroneous vectors

(Method developed by Toru Kouyama at U. Tokyo/ISAS)
Summary

- VCO/Akatsuki will address the unique dynamical state of the Venus atmosphere with systematic sampling of meteorological variables from equatorial orbit.
- Three-dimensional structure of the atmosphere and its temporal variation will be observed by using 4 cameras, a high-speed lightning detector and radio occultation.
- Data processing pipeline is under development. Wind vectors as well as image data and radio occultation data will be released to the public. The dataset will enable quantitative studies of eddy momentum transport and meridional circulation.
The message sheet is put on a table outside of the lecture room.

Don’t miss it! Only names (without messages) are ok.
Titov et al., 2008: Atmospheric structure and dynamics as the cause of ultraviolet markings in the clouds of Venus, Nature 456, 620-623.